Landscape and Urban Planning 169 (2018) 1–11

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Spatial transition analysis: Spatially explicit and evidence-based targets for sustainable energy transition at the local and regional scale

Dirk Oudes[a,b,*], Sven Stremke[a,b]

[a] Wageningen University and Research, Environmental Sciences Group, Landscape Architecture Chair Group, PO Box 47, 6700 AA Wageningen, The Netherlands
[b] Amsterdam Academy of Architecture, Amsterdam University of the Arts, The Netherlands

ARTICLE INFO

Keywords:
Energy landscape
Stakeholder preferences
Energy potential maps
Energy-conscious
Landscape architecture
Landscape planning

ABSTRACT

Climate change, depletion of fossil fuels, and economic concerns are among the main drivers of sustainable energy transition. Over the past decade, several regions with low population density have successfully transited towards renewable energy (for example Siena, Italy). In the Netherlands and other countries, more densely populated regions have drawn up ambitious targets for energy transition. Most of these transition targets lack empirical evidence with regard to spatio-technological feasibility. This lack of evidence may compromise energy transition if constraints are discovered *posteriori* and short-term milestones missed. To address this shortcoming, we propose an integrated approach. *Spatial Transition Analysis (STA)* can assist in defining spatially explicit and evidence-based targets for energy transition. *STA* combines quantitative modelling of energy potentials, qualitative spatial considerations for the siting of renewable energy technologies and comparative scenario development. The application of STA in a case-study (Parkstad Limburg, the Netherlands) revealed that the region has the potential to become energy neutral between 2035 and 2045. Examining and illustrating the different types of constraints as well as the possible choices between renewable energy technologies enabled stakeholders to start planning for energy transition and implementing first interventions. This shows that *STA* provides a solid framework to foster sustainable energy transition initiated by regional stakeholders and informed by local preferences.

1. Introduction

Climate change, depletion of fossil fuels and concerns about local economies are among the main drivers of sustainable energy transition (Bridge, Bouzarovski, Bradshaw, & Eyre, 2013). This transition is not limited to the transformation of energy infrastructure, but involves transformations of “the broader social and economic assemblages that are built around energy production and consumption” (Miller, Iles, & Jones, 2013, p. 135) and is being increasingly studied by social scientists, geographers, spatial planners, landscape architects and other environmental designers (see e.g. Stremke & van den Dobbelsteen, 2013; Sijmons, Hugtenburg, Feddes, & Van Hoorn, 2014). The part of the physical environment affected by energy transition is commonly referred to as ‘energy landscape’ (see e.g. Pasqualetti, 2013; Selman, 2010; Van der Horst & Vermeylen, 2011). In line with the European Landscape Convention, landscape refers to ‘an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors’ (Council of Europe, 2000).

In Europe, several regions have successfully transitioned towards renewable energy, for example Siena, Italy (Casprini, 2013) and Samsø, Denmark (De Waal & Stremke, 2014) – all of which have a low population density. In the Netherlands and other countries, more densely populated regions have defined ambitious targets for energy transition, within a relatively short period of time. Examples in the Netherlands are Stedendriehoek (Pijlman & Bosman, 2014) and the cities Utrecht (Gemeente Utrecht, 2011) and Groningen (Gemeente Groningen, 2008) aiming to achieve 100% energy or carbon neutrality by 2030 or even 2025. Energy neutrality refers to “the extent to which a district […] can supply itself with sustainable energy generated within the boundaries of that district” (Jablonska, Ruijg, Opstelten, & Willems, 2010, p. 1). Regions are often unaware whether spatial characteristics of the region are suitable to achieve energy neutrality (see e.g. “Energietransitienota Duurzame Energie Achterhoek”, 2015; Pijlman & Bosman, 2014). Next, transition targets are often based on little evidence regarding technological feasibility. Furthermore, many targets are conceived without involving stakeholders. Considerations of stakeholders with regard to the way the energy transition should take place are not taken into account. Such bold and superimposed transition targets may compromise energy transition if constraints are discovered *posteriori* and short-term milestones are missed. To illustrate, the target of the municipality

* Corresponding author.
E-mail addresses: dirkoudes@gmail.com (D. Oudes), sven.stremke@wur.nl (S. Stremke).

http://dx.doi.org/10.1016/j.landurbplan.2017.07.018
Received 27 September 2016; Received in revised form 11 July 2017; Accepted 22 July 2017
Available online 16 August 2017
0169-2046/

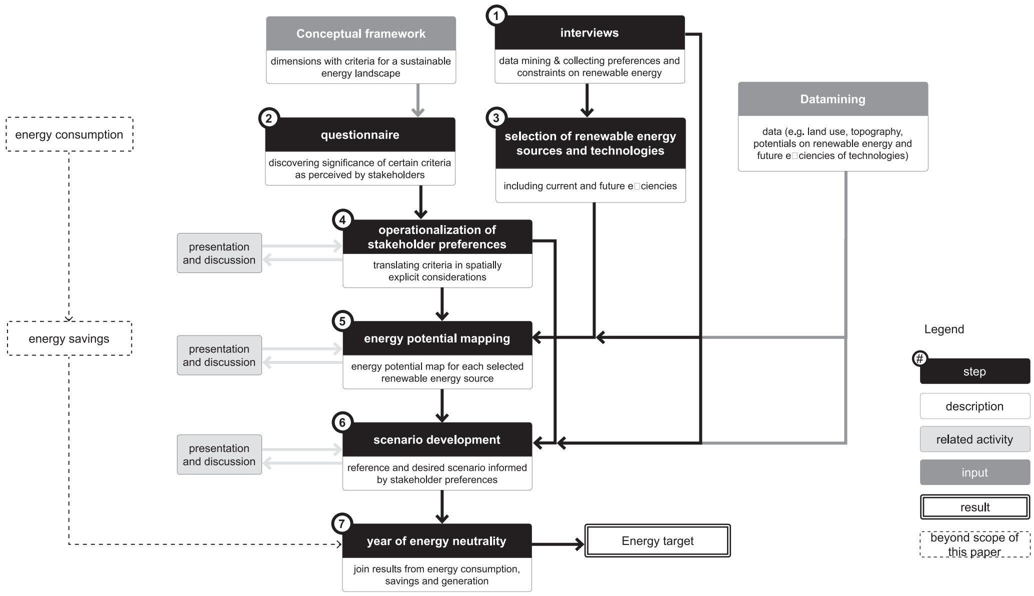


Fig. 1. Methodological framework for Spatial Transition Analysis (STA), revealing the sequence of and links between the seven steps needed to define energy transition targets.

Groningen (the Netherlands) has already been adjusted from 2025 to 2035 (Gemeente Groningen, 2011).

The urgent need to define realistic long-term transition targets and to take action was stressed again by the 2015 Paris Climate Agreement. In the Netherlands, the Dutch NGO *Urgenda*, together with 900 citizens, successfully filed the so-called Climate Case against the Dutch government (Urgenda, 2015). Energy transition has become a key challenge and (inter)national agreements need to be turned into regional and local targets.

To the best knowledge of the authors of this paper, no methodological framework exists that can help define energy transition targets that are spatially explicit, evidence-based, and informed by qualitative stakeholder considerations. The objective of this paper is, therefore, to close this knowledge gap, to present and discuss an integrated approach – *Spatial Transition Analysis (STA)* – that can be used to define targets for regional and local energy transition. To address the shortcomings of current practice, *STA* ought to be spatially explicit, evidence-based with regard to renewable energy technologies (RET), and inclusive of stakeholder values and preferences.

Several concepts, methods and approaches have provided building blocks for the research presented in this paper. Departing from the concept of ‘energy landscape’, Stremke (2015) introduced a conceptual framework for the planning and design of *sustainable* energy transition. He stresses that four dimensions (or types) of criteria should be addressed in the planning and design of sustainable energy landscapes, namely environmental, socio-cultural, economic and technical criteria. This typology will be revisited later in the paper.

Energy Potential Mapping (EPM) offers another building block for energy landscape research. This method is used to map and quantify technical energy potentials (Van den Dobbelsteen, Broersma, & Stremke, 2011). Wang, Mwirigi M’Ikiugu, and Kinoshita (2014) include biophysical and technical constraints that adversely affect renewable energy potentials. Stakeholder preference with regard to renewable energy technologies – another key constraint – is missing however.

Strategic planning and design provided the theoretical foundations of the research presented in this paper (see for example Albrechts, 2004). The *Five Step Approach* is a methodological framework for strategic design that has been applied to envision regional energy landscapes (Stremke, Neven, Boekel, & Koh, 2012). For this, three modes of change, namely current projected trends, critical uncertainties and intended change are integrated in a design process that explores alternative pathways for the realization of transition targets (Stremke, Kann, & Koh, 2012). In this paper the focus is on *how* such targets can be determined.

Advanced methods such as *trade-off analysis* (for example Burgess et al., 2012; Howard et al., 2013) and *multi-criteria decision analysis* (for example Grêt-Regamey & Wissen-Hayek, 2013) are complex and require vast amounts of data and resources. They can play an important role after transition targets have been defined and alternative interventions explored.

For the research presented here, literature studies and a case study (Yin, 2009) have been conducted. Insights from other closely related projects in the Netherlands, Germany, Austria and Denmark have been incorporated (for example, De Waal & Stremke, 2014). A case study was carried out in the Parkstad Limburg region (The Netherlands). The area selected consists of an agglomeration of three mid-sized cities and five rural municipalities. The research process was iterative in character and conducted in close collaboration with the regional and local initiators of energy transition as well as other stakeholders.

The second section of this paper delineates the methodological framework that can be employed to define energy targets. The third section illustrates these steps making use of materials and results from the *Parkstad Limburg Energy Transition (PALET)* project. Finally, the approach and the results are discussed in section four and conclusions drawn in section five.

2. Methodological framework for spatial transition analysis (STA)

This section gives a brief description of the methods and techniques needed to define energy targets at the regional or local level. The overall methodological framework and the links between the different steps are illustrated in Fig. 1. The aim, execution, input and output of each of the seven STA steps are addressed in the following sub-sections.

2.1. Interviews

One of the aims of conducting interviews with local stakeholders is to gather spatially explicit data on potentials, constraints and the existing supply of renewable energy sources. Another aim is to collect information on stakeholder preference and aversion regarding RET. The output may consist of local (GIS) data, municipal development plans, annotated topographical maps as well as documents listing preference and aversion to RET.

2.2. Questionnaire

The aim of the questionnaire was to discover the significance of certain criteria for sustainable energy transition, as perceived by the stakeholders. Their preferences are operationalized in Step Four and inform the scenario development in Step Six. Departing from a long-list of 40+ sustainability criteria (Stremke, 2015), sixteen criteria applicable for energy transition in Parkstad Limburg were selected for the PALET questionnaire. Respondents were civil servants and aldermen from the eight municipalities and the regional government. They were asked to rate each criterion on a scale of 1 (not important) to 5 (important).

2.3. Selection of renewable energy sources and technologies

The aim of Step Three is to determine potential renewable energy sources and technologies for the transition. In order to develop a robust energy system, multiple sources and alternative technologies for each source are to be included (Stremke & Koh, 2011). Given the aim of the research – to define an evidence based target – only proven energy technologies are included and sufficient data on renewable energy potentials of these technologies must be available.

For PALET, a preliminary analysis of existing data on renewable energy sources was conducted and proven technologies listed. For example, the number of solar hours per year and spatial data on building typology to determine the potential of photovoltaic (PV) panels on rooftops. A definitive selection of renewable energy sources and technologies was made in collaboration with technology experts and key stakeholders. Data and spatial information were included in the mapping study (Step Five). Current and expected efficiencies of renewable energy technologies were derived from literature available. The output of Step Three is a list of technologies and efficiencies clustered according to energy sources.

2.4. Operationalization of stakeholder preferences

The aim of Step Four is to operationalize qualitative sustainability criteria, making them spatially explicit. The conceptual framework for the development of sustainable energy landscapes can help here (see Fig. 2). For each study, criteria have to be defined and prioritized by stakeholders in collaboration with experts. In order to develop a sustainable energy landscape and prevent land use competition, stakeholders might want to limit the area made available for PV farms. Data used in completing this step is the result of the interviews (Step One) and the questionnaire (Step Two), as well as notes from discussions and literature. The output is a list of spatially explicit considerations to be used as input for the process of mapping energy potential (Step Five) and scenario development (Step Six). An example is presented in Section 3.4.

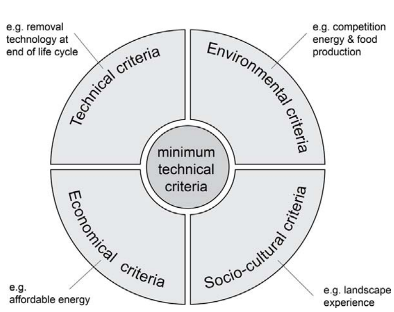


Fig. 2. Conceptual framework for the planning and design of sustainable energy landscapes (Stremke, 2015).

2.5. Energy potential mapping

The aim of Step Five is to map renewable energy potentials and constraints. These are differentiated according to land use categories. In PALET, these included residential area, public services, commercial services as well as areas being used for industry and transport, for example. Using the GIS software ArcGIS, each potential and constraint is defined as layer, edited, organized and visualised. GIS datasets may contain general topographical information about land use and relief for example and constraints to renewable energy technologies such as soil protection areas and Natura 2000 areas. Additional data, such as the locations of fallow land and sound barriers, came from the interviews (Step One). Data on numerical potentials of renewable sources, for example, solar irradiation and wind speed 100 m above ground level were inserted into the GIS. The output of Step Five is a GIS model and a map for each renewable energy source, containing specific information about the potentials and constraints of the preselected energy technologies.

2.6. Scenario development

The aim of Step Six is to compute the potential for renewable energy generation in petajoules (PJ) and to indicate the relative effects of each constraint. To do this, two scenarios are developed: a 'reference scenario' which incorporates technical constraints only and a 'desired scenario' based on stakeholder preferences and expert knowledge (see Fig. 3). The former scenario establishes a reference, which is the maximum technical potential for renewable energy generation (Blaschke, Biberacher, Gadocha, & Schardinger, 2013). The latter scenario reveals the effects of stakeholder preferences and provides a realistic image of renewable energy potentials. Information from interviews (Step One) and questionnaire (Step Two) along with spatial explicit considerations (Step Four) make the input for scenario development.

In PALET, flowcharts were used to reveal the relationships between potentials and constraints of each selected RET. They provided the basis for the creation of the scenarios and calculations. Spreadsheet software (Microsoft Excel) was used to organize and calculate the amount of renewable energy provision. The output of Step Six is an overview of renewable energy provision organized by source and technology. This is communicated through flowcharts, tables, textual description, bar

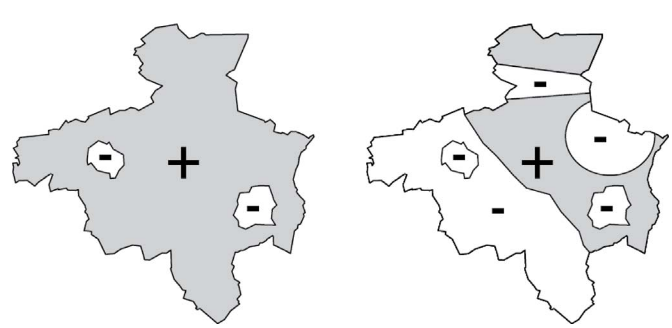


Fig. 3. Conceptual visualization of the differences between 'reference scenario' (left) and 'desired scenario' (right). In this figure the plus symbol represents the potential area for renewable energy, while the minus symbol represents the constraints. In the 'reference scenario' only technical constraints are incorporated, while the 'desired scenario' shows the effects of stakeholder preferences and provides a more realistic image of renewable energy potentials.

Fig. 4. Geographical location of Parkstad Limburg in the south of the Netherlands (above left) and map of the eight municipalities that together constitute the region.

charts and infographics.

2.7. Year of energy neutrality

The aim of Step Seven is to link the results of the renewable energy study (as presented in this paper) with the current energy consumption and potential energy savings. Together, they make it possible to determine the possible year of energy neutrality. Implementation time may differ per renewable energy technology, ranging from one or two years for solar panels up to ten years for large wind parks in the Netherlands (Hekkenberg & Lensink, 2013). Taking this into account, an s-curve that is typical for technology diffusion (i.e. take-off, acceleration and stabilization phase) was applied in PALET to estimate the year of energy neutrality. When local renewable energy provision exceeds local energy consumption, energy neutrality is achieved. Data used in this step are the results from Step Six (desired scenario) and from the energy savings study. The outcome of Step Seven is an indication of the potential year of energy neutrality for a study area.

3. Case study Parkstad Limburg

Our case study – Parkstad Limburg – is a region in the south of the Netherlands (see Fig. 4) consisting of eight municipalities. It is an agglomeration of three mid-sized cities and five rural municipalities. It has a surface area of 211 km^2 and some 255,000 inhabitants (1208 inhabitants/km^2). Compared to the rest of the Netherlands, it has an atypical landscape, consisting of large plateaus and wide river valleys. Parkstad Limburg is experiencing demographic shrinkage (CBS, 2009a) and declining employment opportunities (CBS, 2009b). The PALET project was commissioned by the regional government and executed by three parties. Zuyd University studied the current energy demand and potential energy savings, H + N + S landscape architects coordinated the project, while the authors of this paper examined the renewable energy potentials. A group of representatives from the municipal and regional authorities informed the project and reflected on the process. The research was conducted in the first half of 2014. With regards to the four key elements of successful transitions (Loorbach & Rotmans, 2010), the project contributed to the creation of a *transition arena,* as well as to the establishment of a shared *transition agenda* in Parkstad Limburg. Note that *implementation* and *monitoring* are part of ongoing follow-up projects that are beyond the scope of this paper.

Section Three illustrates the application of STA in the Parkstad Limburg region. The sequence of sub-sections corresponds with that of Section Two. Solar energy technologies that convert solar irradiation into electricity and heat are used to exemplify the STA approach.

3.1. Interviews

The interviews were semi-structured and involved eighteen representatives from the eight municipalities and the regional government. Interviewees were asked about the current status-quo and ideas for energy transition in each municipality. The interviewees offered spatial data with different levels of detail, for example CAD drawings of fallow terrains and strategic visions. They reported that selected policy constraints for renewable energy were available in GIS format for the entire province – a consistent data set for all municipalities. Interviewees also suggested various ideas for siting renewable energy technologies, for example, the construction of PV panels on sound barriers of a new highway. The interviews revealed many relevant insights. Some of the data, however, turned out to be too detailed for research on the regional energy target but were used in subsequent projects.

Table 1
Overview of results from the PALET questionnaire: the four dimensions of sustainability, criteria and scores (bandwidth and average; 1 indicating 'not important' and 5 'important').

Dimension	Criterion questionnaire	Lowest score	Highest score	Average score
Technical	Make use of renewable energy sources	4	5	4.8
	Employ locally available energy	2	5	4.4
	Aim for a diversified energy system	1	5	4.2
	Aim for a self-sufficient energy landscape	3	5	4.5
Environmental	Reduction of harmful emissions	3	5	4.4
	Do not compete with food production	3	5	4.3
	Preserve/improve biodiversity	4	5	4.6
	Preserve other ecosystem services	3	5	4.8
Socio-cultural	Attractive landscape	3	5	4.7
	Preserve sites with cultural heritage value	2	5	4.6
	Maintain (or improve) potentials for recreation and ecotourism	1	5	3.7
Economical	Access to affordable energy	2	5	4.1
	Minimize land-use competition	1	5	3.9
	Create local and regional jobs	4	5	4.6
	Maintain/improve secure energy supply	2	5	4.4
	Economic feasibility	2	5	4.6

Table 2
Overview of renewable energy sources and technologies that were selected for PALET. For biomass, types of biomass are described instead of technologies.

Renewable energy source (RES)	Renewable energy technology (RET)
Solar energy	Photo-voltaic (PV) panels
	Solar thermal collector
	Asphalt solar collector
Wind energy	Wind turbine
	Small building-integrated wind turbine
Heat-cold storage	Open system
	Closed system
	Mijnwater 2.0 (heat-cold exchange by means of local old mineshafts)
Hydropower	Small hydropower system
Biomass	Waste gas
	Manure
	Verge clippings
	Woody biomass
	Straw
	Energy crop

3.2. Questionnaire

A total of 39 people responded to the questionnaire, among whom were civil servants and alder(wo)men. The results of the questionnaire are depicted in Table 1. The ‘use of renewable energy sources’, ‘economic feasibility’ and the ‘preservation of cultural heritage sites’ were considered important criteria that should be taken into account for the sustainable energy transition in this region. Other criteria such as ‘minimize land use competition’ and ‘maintain potentials for recreation and ecotourism’ were considered important to some extent. The relatively high average of criteria indicates a desire to develop a sustainable energy landscape, even though some respondents considered particular criteria less important than others. Clearly, there is consensus and a positive attitude towards the use of locally available renewable energy sources. Landscapes with high scenic values should be considered carefully during the transition.

3.3. Selection of renewable energy sources and technologies

Five renewable energy sources were studied in detail for the Parkstad Limburg region: solar, wind, heat-cold storage, hydropower and biomass. Deep geothermal energy was excluded for two reasons: a lack of reliable data on geothermal potential and the very low potential indicated in the few references that were available. For each of the five energy sources, renewable energy technologies were selected (Table 2). For solar energy, the technologies were PV panels, solar thermal collectors and asphalt solar collectors. For each technology, efficiencies and their expected increase in efficiency were derived from literature (see Table 3). To calculate the future efficiencies of PV cells, estimations for the three most prominent techniques were averaged. If solid indicators for future efficiencies were absent, the current efficiency was used.

Table 3
Overview of conversion efficiencies for selected solar energy technologies.
Source: NREL (2013) and Mehalic (2009).

Current and future efficiencies	2014	2020	2030	2040	2050
Photovoltaic panels	15%	18%	22%	27%	30%
Solar thermal collectors	35%	39%	45%	51%	56%
Asphalt solar collectors	25%	25%	25%	25%	25%

3.4. Operationalization of stakeholder preferences

For solar energy, the physical potentials and constraints, technical requirements and stakeholder preferences were made spatially explicit. A complete overview of constraints that limit the potential of renewable energy generation can be found in Appendix A. For PV farms on agricultural land, for example, constraints are (1) *unfit shape of terrain*, (2) *parcels with northern orientation*, (3) *parcels with steep slope*,(4) *competition with food production* and (5) *parcels within protected landscape*. The importance of *food production* to the stakeholders and experts resulted in the exclusion of 90% of agricultural land from being used as PV farms. The remainder might become available due to continuous improvements in agricultural practice in the Netherlands (computed on the basis of historical trends). The high importance of the socio-cultural criterion *aesthetic value/landscape experience* affects the potential for placing PV panels and solar thermal collectors. Half of the settlements with heritage status – the most visible part – and all cultural heritage buildings were excluded. Because of the importance of the socio-cultural criterion *recreation and ecotourism,* lakes used for leisure purposes were exempt from floating PV farms. Note that not all criteria studied in the questionnaire resulted in spatially explicit constraints. Some questions simply served to facilitate an understanding of the motivation for energy transition in the region.

During this phase of the research, four types of constraints that would affect the introduction of renewable energy technologies were identified; they can be classified as following:

- Physical constraints that inhibit the implementation of a specific technology, for example, northern orientation of slopes inhibiting the installation of PV farms.
- Exogenous policy constraints that are dictated from outside the region, formalized in legislation and therefore difficult to change for regional stakeholders. For example, low flying zones for air traffic which prohibit the installation of large wind turbines.
- Endogenous policy constraints that are formalized in regional or local legislation. The responsible legal bodies within the study area can change constraints such as the heritage status of certain settlements.
- Normative constraints that are not (yet) formalized in legislation, but reflect the sentiment or negative attitude of regional stakeholders towards certain RET or RET locations.

The number and type of constraints differ per technology. PV farms in Parkstad Limburg, for example, are affected by five constraints – three physical and two normative (see Fig. 5). Placing the different constraints within the conceptual diagram for sustainable energy landscapes enables stakeholders to better understand the number and types of constraints for each technology.

3.5. Energy potential mapping

For solar and wind energy, heat-cold storage, hydropower and biomass, the potentials and constraints were illustrated in one map each (1:25.000). Fig. 6 shows the map that was created for solar energy. This map indicates that the entire region falls within a zone of 1450–1500 h of sunshine per year. Roofs of residential, public and commercial buildings and industrial plants are suitable for both PV panels and solar thermal collectors. The map depicts settlements with heritage status as well as landmarked buildings. Open water offers potential for floating PV farms, except where lakes are being used for leisure purposes. In general, agricultural land can host PV farms, so can sand mining areas and landfill sites. Note that a 10% rule for agricultural land is applied. The National Landscape South-Limburg – a large part of the region – is

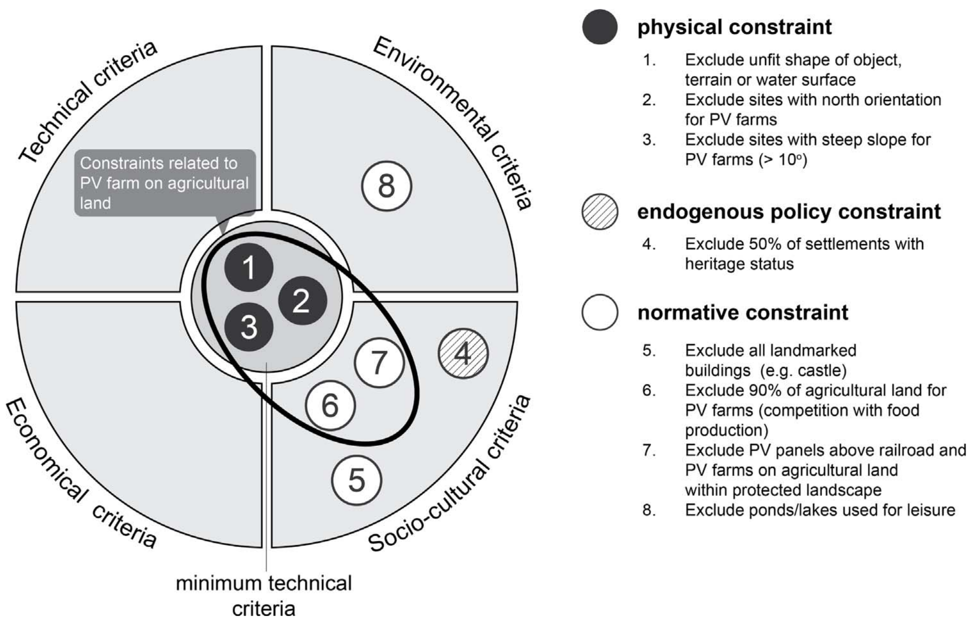


Fig. 5. Overview of constraints for selected solar energy technologies. The figure reveals how a set of specific constraints to renewable energy technologies can be linked to the dimensions of sustainability. The black outline indicates the constraints related to the technology PV farm.

not suited for PV farms. The Northern part of the region contains large areas of forest, which are also excluded. In the medium- to long-term, asphalt solar collectors can be integrated into the roads. PV panels can be integrated in new road structures, above railways and in (a portion of) the vertical surface of sound barriers along the highway that is being constructed.

3.6. Scenario development

In the *reference scenario,* the total renewable energy potential is 69 PJ. In the *desired scenario,* the renewable energy potential amounts to 20 PJ. The flowcharts in Appendix B and C show the solar energy potentials and constraints that were included in the reference and desired scenario respectively. The large difference in solar energy potential

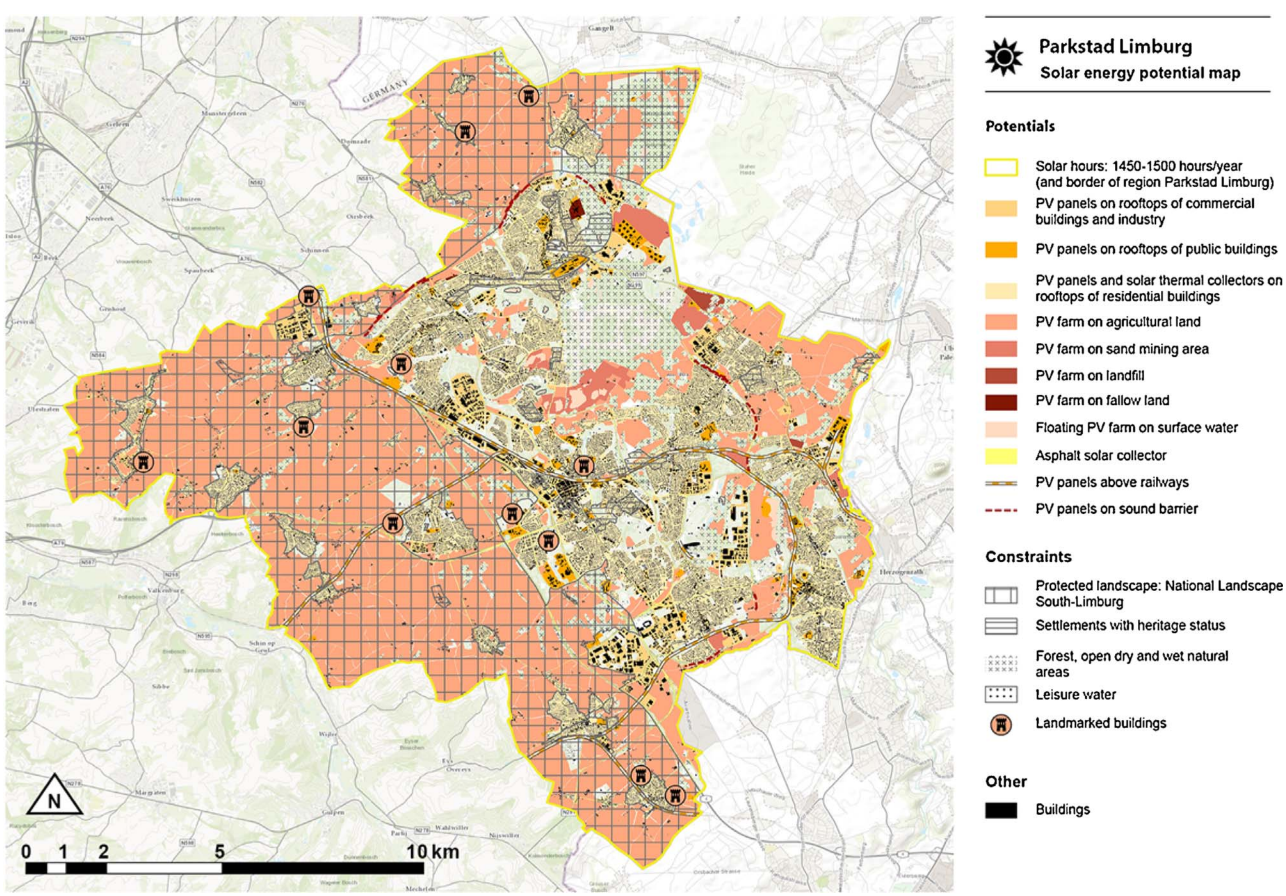


Fig. 6. Solar energy potential map of Parkstad Limburg.

between the two scenarios is mainly the result of the fact that 90% of the agricultural land is excluded for PV farms in the desired scenario. Appendix A shows how each constraint affects the overall provision of solar energy in the desired scenario.

3.7. Year of energy neutrality

The energy consumption in Parkstad Limburg was 30 PJ in 2012 while the potential energy savings amount to 16 PJ (Bongers, Broers, Janssen, Kimman, & Weusten, 2014). Combining the results of both studies, the year of potential energy neutrality has been estimated anytime between 2035 and 2045 (*desired scenario),* making use of non-linear technology diffusion rates. Societal and economic developments as well as other factors such as technological breakthroughs will influence the energy transition and prohibit the prediction of a specific year of energy neutrality.

The renewable energy portfolio of Parkstad Limburg in the desired scenario consists largely of solar energy (51.5%) and heat-cold storage (40.7%). Wind energy (5.6%) is very limited due to policy and normative constraints. Biomass (2%) contributes relatively little and consists of second-generation biomass only. Yet, even in the *reference scenario*, the use of energy crops on arable land only doubles the biomass potential (4%). Hydropower (0.2%) has a very low potential in Parkstad Limburg because height differences are small.

Regional energy potentials exceed the expected demand for electricity by 19% and heat for 85%. More and more transport will make use of renewable electricity but the region is unable to generate the remaining demand of fossil fuel for transport. The required import of fossil fuels would need to be compensated by export of renewable electricity as is being done, for example on Samsø, Denmark.

To some extent, the renewable energy portfolio is flexible with regard to technologies. For example, PV farms could substitute wind turbines. This flexibility is important for stakeholders as it enables them to deal with changing societal preferences as well as technological advancements. Slower deployment of renewable energy technologies and/or implementation of energy saving measures would push back the year of energy-neutrality in Parkstad Limburg and other places where STA is employed to establish spatially explicit and evidence-based targets for energy transition.

4. Discussion

In this section, we will discuss data, spatial extent and stakeholder interaction of the case study. We will then look at the similarities and differences between STA and other spatial approaches to sustainable energy transition.

4.1. Data and level of detail

Researching the spatially explicit potentials for multiple renewable energy sources and technologies in a region of more than 200 km^2 requires a large amount of reliable data. This dependency on accurate and up-to-date GIS data, for example, can become an issue in countries where such data is incomplete or unavailable. Furthermore, the research is based on scientific literature with regards to the future efficiencies of energy technologies. Therefore, the potential year of energy self-sufficiency should be considered an estimate rather than a fact. Additional data such as demographic trends can strengthen the evidence-based character of STA studies.

Thanks to the iterative research process, two scenarios turned out to be sufficient for PALET. Depending on the characteristics of the physical environment and stakeholder preferences, more scenarios (i.e. different sets of constraints) might be needed in other STAs. Dynamic GIS models enable quick exploration of additional scenarios. The dynamic GIS model that was created for PALET is being used in the follow-up projects. PALET 2.0 provides insights into the potential for energy saving and renewable energy generation for each municipality individually. The model is also being used in PALET 3.0 to determine short-term targets and support mutual agreements between the eight municipalities.

4.2. Spatial extent and energy neutrality

The spatial extent of PALET was determined on the basis of existing collaborations between the eight municipalities. This is certainly beneficial for the management of the energy transition process as the different administrations were used to joining forces. However, this spatial delineation remains somewhat arbitrary since the collaboration with other regions may provide additional value in the light of energy transition. Electricity exchange, for example, could help to deal with the intermittent character of wind and solar energy. It remains to stress that energy neutral regions, as opposed to autarkic regions, are well connected with other regions in order to create robust energy systems.

4.3. Stakeholders, interaction and preferences

The excellent interaction with commissioners and representatives from the municipalities enabled the PALET research process to proceed smoothly. This may not be the case in all regions, while we see it as a prerequisite of any similar study. Others have argued rightfully about the importance of capacity building in fostering energy transition (see, for example, Trutnevyte, Stauffacher, & Scholz, 2011). Stakeholders learn about energy, technologies and get to know others involved in the transition. Projects such as PALET are important for researchers too, because they allow the testing of theoretical concepts and frameworks.

Due to limited time, the questionnaire was only distributed to alder (wo)men and civil servants. For more inclusive results, inhabitants, entrepreneurs and non-governmental organisations need to participate. In Parkstad Limburg, this is being addressed in follow-up projects. The translation of qualitative results from stakeholder inquiry towards quantitative scenarios required different degrees of interpretation. The outcome of the questionnaire directly affected some choices during the scenario development, for example the protection of scenic landscape. More specific and elaborated questionnaires may be beneficial for future projects.

Some of the constraints that play a role in the STA can be considered flexible in the medium to long term. Responsibilities for present-day exogenous policy constraints, for example, may be delegated to local governments in the future, as a consequence of decentralisation. Furthermore, constraints that are currently normative in character could become part of local or regional policies once there is a consensus among stakeholders. In addition, attitudes towards renewable energy technologies may change in time due to new insights, changing value systems or other factors (see e.g. ETSU, 1993). Therefore, it is suggested to monitor developments throughout the transition and adjust measures where needed.

4.4. Similarities and differences between STA and other approaches

This paper shows how a target for energy transition can be established by researching the potentials for renewable energy provision and energy savings. Qualitative considerations of stakeholders and experts are included in the STA, together with the particular bio-physical characteristics of Parkstad Limburg. In doing so STA expands on the

work of Wang et al. (2014) who studied the potential degree of self-sufficiency without stakeholder preferences. Blaschke et al. (2013) too uses GIS maps and distinguishes between 'technical' and 'realistic' potentials. The latter, however, is solely based on expert judgement and not informed by stakeholder preferences. Similar to Van den Dobbelsteen et al. (2011), STA illustrates renewable energy potentials through maps. The dynamic GIS model and inclusion of stakeholder preference are two differentiating characteristics of STA. Other research such as the visual assessment of potential interventions (see e.g. Grêt-Regamey & Wissen-Hayek, 2013) can be carried out once the energy transition target has been established. In Parkstad Limburg, the STA was conducted in a relatively short amount of time and at an early phase of the regional energy transition. As a matter of fact, it marked the start of the planning process. The research provided the foundations for a joint political ambition (the target) while contributing to capacity building in the region. If reliable (GIS) data is available and active stakeholder participation incorporated, STA may prove to be beneficial to support the energy transition process in other countries.

5. Conclusions

The main objective of the research presented in this paper was to advance the study of spatially explicit and evidence-based targets for sustainable energy transition at the regional and local scale. This paper focuses on the study of renewable energy potentials informed by qualitative stakeholder considerations. The potentials for energy savings should be studied in parallel (see for example Bongers et al., 2014).

The proposed methodological framework – Spatial Transition Analysis (STA) – employs quantitative techniques to model renewable energy potentials, takes qualitative considerations into account and unravels the variables that influence both the transition target and the time needed to reach energy neutrality. In doing so, STA allows for the exploration of alternative transition paths.

The paper illustrates that Parkstad Limburg has the potential to become energy neutral anytime between 2035 and 2045. This finding is of great value to the stakeholders; short-term actions have been initiated and medium to long-term actions discussed actively. Moreover, findings are expected to facilitate the evaluation of existing policies or even the design of new policies. Empirical data, scenarios and dynamic models reveal the direct relationships between the local landscape characteristics, stakeholder values and renewable energy potentials. In addition, STA can help to explicate how particular sustainability criteria and associated stakeholder preferences may influence the choice and location of renewable energy technologies. This enables stakeholders to start planning for energy transition and implementing first interventions. STA therefore provides a solid approach fostering a *sustainable* energy transition, initiated by regional stakeholders and informed by local preferences.

As opposed to current mainstream practice, STA aids a thorough understanding of qualitative aspects at an early stage of energy transition process, without limiting the discussion to a small number of economically interesting technologies. Opposition towards certain renewable energy technologies is expected to be less fierce when qualitative aspects have been considered at an early stage. Continuous research in Parkstad Limburg will, among others, allow the examination of this assertion.

The (region-specific) trade-offs between qualitative considerations and economic aspects, for example pay-back time, deserve further attention. However, what has already become clear through the research in Parkstad Limburg is that more qualitative considerations are likely to increase the financial costs of the transition. Constructing fewer wind turbines, for example, can help to maintain landscape scenery while alternative technologies are more cost intensive.

Close collaboration with social scientists is needed to further strengthen stakeholder interaction. This applies to energy transition in general and spatially explicit approaches such as STA in particular. Further research is needed on the role of landscape architects and other environmental designers in energy transition processes. Creative inquiry into alternative futures – a key contribution of environmental designers to energy transition – may be fostered by scenario design (see e.g. Weller, 2008) and research through design approaches (see e.g. Lenzholzer, Duchhart, & Koh, 2013).

For transitions at a regional level, such as Parkstad Limburg, it is important to acknowledge and connect with already existing local initiatives and to foster the emergence of a transition community consisting of citizens, entrepreneurs and other (semi-public) organisations. Initiatives such as PALET can provide inspiration and serve as a reference to others – a region-specific knowledge base that empowers local initiatives while addressing global challenges.

Acknowledgments

The authors like to thank the representatives of Parkstad Limburg for their enthusiasm and learning attitude with regard to sustainable energy transition. Next, we would like to thank the project partners Zuyd University, H + N + S landscape architects and Siebe Broersma from TU Delft. We also like to thank Renée de Waal for reviewing the first manuscript. Last but not least, we thank the anonymous peers for reviewing the manuscript.

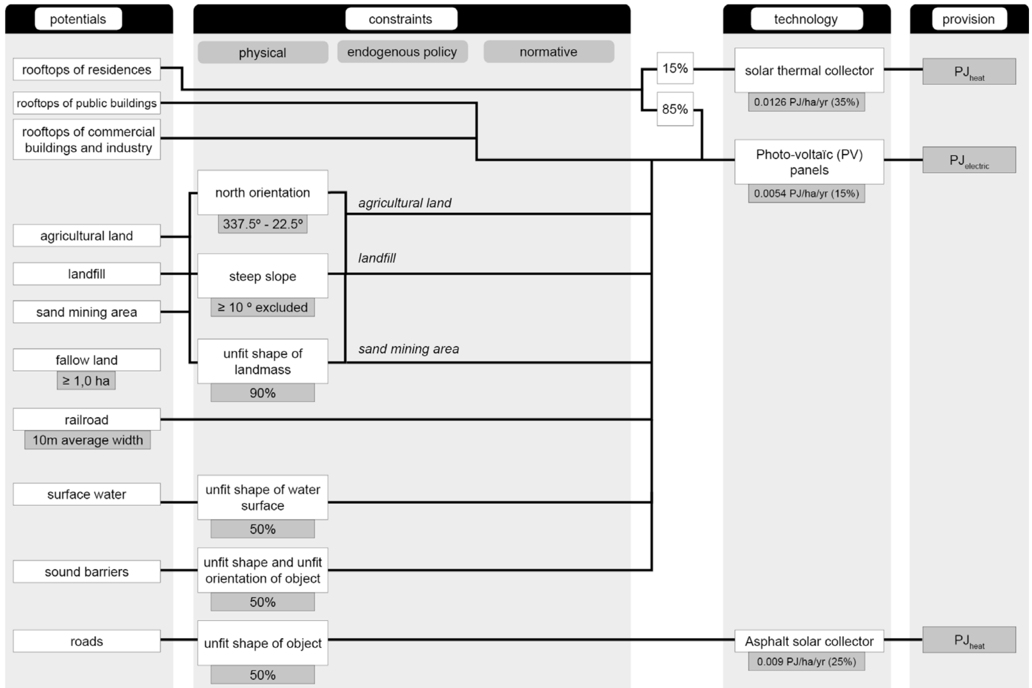
Appendix A

See Table A1.

Table A1
Relative influence of constraints per solar technology (influence of specific constraints over total influence of constraints) in the Parkstad Limburg region.

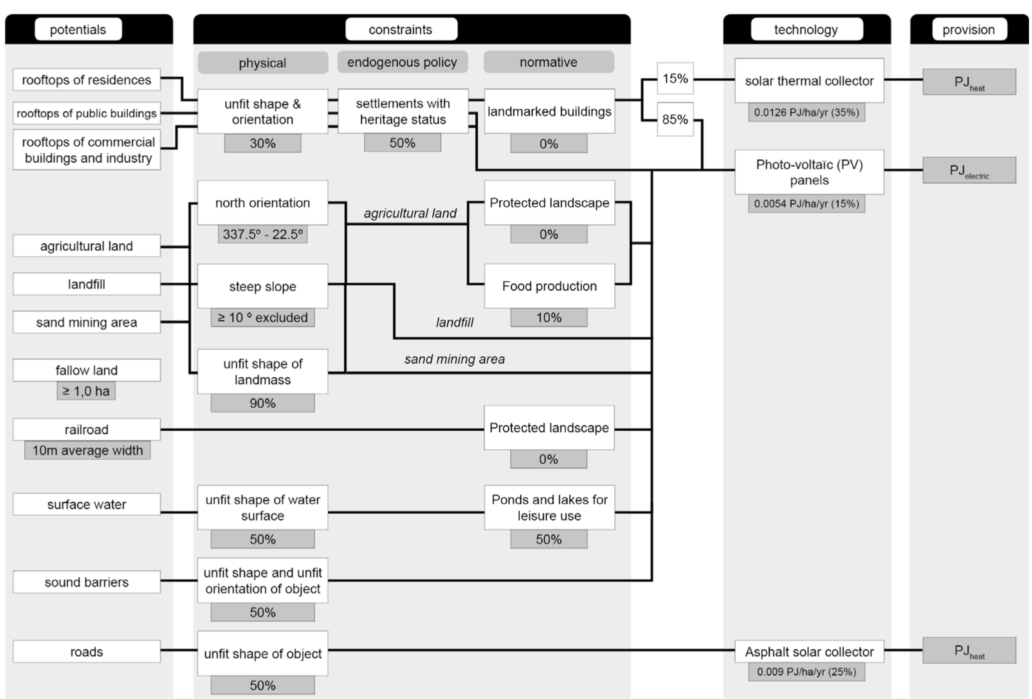
Technology	Location/land use	Type of mconstraint	Constraint	Gross potential (petajoule)	Reduced potential (petajoule)	Influence of constraint (%)
Asphalt collector	Roads	physical	unfit shape of object		2,37	100%
			Subtotal	**4,97**	**2,37**	**100%**
Solar thermal collector	Rooftops of residential buildings	physical	unfit shape and unfit orientation of building		0,89	96%
		endogenous policy	settlements with heritage status		0,03	3%
		normative	landmarked buildings (castles)		< 0,01	1%
			Subtotal	**1,62**	**0,92**	**100%**
PV panels	Rooftops of residential buildings	physical	unfit shape and unfit orientation of building		5,04	96%
		endogenous policy	settlements with heritage status		0,16	3%
		normative	landmarked buildings (castles)		0,03	1%
			Subtotal	**7,20**	**5,23**	**100%**
	Rooftops of commercial buildings and industry	physical	unfit shape and unfit orientation of building		1,11	99,0%
		endogenous policy	settlements with heritage status		< 0,01	1,0%
			Subtotal	**2,76**	**1,11**	**100%**
	Rooftops of public buildings	physical	unfit shape and unfit orientation of building		0,23	98%
		endogenous policy	settlements with heritage status		< 0,01	2%
			Subtotal	**0,58**	**0,24**	**100%**
	Agricultural land	normative	Protected landscape: national landscape South-Limburg		53,96	66%
		physical	north orientation		14,33	17%
		normative	food production		9,86	12%
		physical	steep slope		2,96	4%
		physical	unfit shape of terrain		1,22	1%
			Subtotal	**83,42**	**82,33**	**100%**
	Fallow land	physical	unfit shape of terrain		0,01	100%
			Subtotal	**0,12**	**0,01**	**100%**
	Sand mining area	physical	slope		0,76	63%
		physical	north orientation		0,28	23%
		physical	unfit shape of terrain		0,16	13%
			Subtotal	**2,61**	**1,20**	**100%**
	Landfill	physical	slope		0,05	49%
		physical	north orientation		0,04	35%
		physical	unfit shape of terrain		0,02	16%
			Subtotal	**0,27**	**0,11**	**100%**
	Railway tracks	normative	Protected landscape: national landscape South-Limburg		0,18	100%
			Subtotal	**0,52**	**0,18**	**100%**
	Surface water	physical	unfit shape of water surface		0,46	64%
		normative	ponds and lakes for leisure use		0,26	36%
			Subtotal	**1,05**	**0,72**	**100%**
	Sound barriers	physical	unfit shape and unfit orientation of object		0,01	100%
			Subtotal	**0,02**	**0,01**	**100%**
Total				105,17	94,43	

Appendix B



Flowchart for solar energy in the reference scenario.

Appendix C



Flowchart for solar energy in the desired scenario.

References

Albrechts, L. (2004). Strategic (spatial) planning re-examined. *Environment and Planning B: Planning and Design*, *31*, 743–758.

Blaschke, T., Biberacher, M., Gadocha, S., & Schardinger, I. (2013). Energy landscapes: Meeting energy demands and human aspirations. *Biomass Bioenergy*, *55*, 3–16.

Bongers, J., Broers, W., Janssen, F., Kimman, J., & Weusten, P. (2014). *Parkstad Limburg Energietransitie (PALET) Achtergronddocument 1*. Heerlen: Zuyd Hogeschool.

Bridge, G., Bouzarovski, S., Bradshaw, M., & Eyre, N. (2013). Geographies of energy

transition: Space, place and the low-carbon economy. *Energy Policy*, *53*, 331–340.
Burgess, P. J., Rivas Casado, M., Gavu, J., Mead, M., Cockerill, T., Lord, R., et al. (2012). A framework for reviewing the trade-offs between renewable energy, food, feed and wood production at a local level. *Renewable & Sustainable Energy Reviews*, *16*(1), 129–142.
CBS (2009a). *Regionale prognose 2009–2040: Vergrijzing en omslag van groei naar krimp (Regional forecast 2009–2040: Agedness and turning from growth to shrinkage)*. Heerlen: Centraal Bureau voor de Statistiek.
CBS (2009b). *De verborgen aantrekkingskracht van Parkstad-Limburg (The hidden attraction of Parkstad Limburg)*. Heerlen: Centraal Bureau voor de Statistiek.
Casprini, P. (2013). *Siena carbon free. Goal reached*. Retrieved on 8th of July from http://www.provincia.siena.it/var/prov/storage/original/application/395f72cc44c6d83188ca1d561cf453be.pdf.
Council of Europe (2000). *European landscape convention, European treaty series – No. 176*. Retrieved from https://rm.coe.int/1680080621.
De Waal, R. M., & Stremke, S. (2014). Energy transition: Missed opportunities and emerging challenges for landscape planning and designing. *Sustainability*, *6*, 4386–4415.
Energy Technology Support Unit (ETSU) (1993). *Attitudes toward windpower: A survey of opinion in Cornwall and Devon. ETSU report W/13/00 354/038/REP*Harwell: Energy Technology Support Unit (ETSU).
Energietransitienota Duurzame Energie Achterhoek (2015). Retrieved on 8th of July 2017 from https://www.oostgelre.nl/bestand/energietransitienota-duurzame-energie-achterhoek.
Gemeente Groningen (2008). *Routekaart Groningen Energieneutraal 2025 (Roadmap Groningen Energy neutral 2025*. Retrieved on 8th of July 2017 from https://refman.energytransitionmodel.com/publications/1498.
Gemeente Groningen (2011). *Masterplan Groningen Energieneutraal (Masterplan Groningen Energy neutral)*. Retrieved on 8th of July 2017 from https://gemeente.groningen.nl/groningen-geeft-energie.
Gemeente Utrecht, Programma Utrechtse energie 2011–2014 (Energy Program of Utrecht 2011–2014), 2011, Retrieved 26th of July 2017 from https://www.utrecht.nl/fileadmin/uploads/documenten/9.digitaalloket/Milieu/Programma-Utrechtse-Energie-definitief.pdf.
Grêt-Regamey, A., & Wissen-Hayek, U. (2013). Multicriteria decision analysis for the planning and design of sustainable energy landscapes. In S. Stremke, & A. van den Dobbelsteen (Eds.), *Sustainable energy landscapes: Designing, planning and development* (pp. 111–132). Boca Raton: CRC Press.
Hekkenberg, M., & Lensink, S. M. (2013). *16% hernieuwbare energie in 2020–wanneer aanbesteden? (16% renewable energy in 2020–when to put out to tender?) (ECN 6.00661). ECN*. Retrieved from https://zoek.officielebekendmakingen.nl/blg-212445.pdf.
Howard, D. C., Burgess, P. J., Butler, S. J., Carver, S. J., Cockerill, T., Coleby, A. M., et al. (2013). Energyscapes: Linking the energy system and ecosystem services in real landscapes. *Biomass and Bioenergy*, *55*, 17–26.
Jablonska, B., Ruijg, G. J., Opstelten, I. J., & Willems, E. (2010). Innovative concepts for energy neutral districts in 2050 (conference paper). *AES2010 conference*.
Lenzholzer, S., Duchhart, I., & Koh, J. (2013). 'Research through designing' in landscape architecture. *Landscape and Urban Planning*, *113*, 120–127. http://dx.doi.org/10.1016/j.landurbplan.2013.02.003.
Loorbach, D., & Rotmans, J. (2010). The practice of transition management: Examples and lessons from four distinct cases. *Futures*, *42*(3), 237–246. http://dx.doi.org/10.1016/j.futures.2009.11.009 Online first.
Mehalic, B. (2009). *Flat-plate & evacuated-tube solar thermal collectors*. Retrieved October 8, 2013 from http://www.homepower.com/articles/solar-water-heating/equipment-products/flat-plate-evacuated-tube-solar-thermal-collectors.
Miller, C. A., Iles, A., & Jones, C. F. (2013). The social dimensions of energy transitions: Introduction to the special issue. *Science and Culture*, *22*, 135–148.
NREL (2013). *National center for photovoltaics*. Retrieved October 8, 2013 from http://www.nrel.gov/ncpv/images/efficiency_chart.jpg.
Pasqualetti, M. J. (2013). Reading the changing landscape. In S. Stremke, & A. van den Dobbelsteen (Eds.), *Sustainable energy landscapes: Designing, planning and development* (pp. 11–44). Boca Raton: CRC Press.
Pijlman, J., & Bosman, R. (2014). *Nieuwe energie voor de Stedendriehoek. Routekaart naar een energieneutrale regio Stedendriehoek in 2030 (New energy for the Stedendriehoek. Roadmap towards an energy neutral region Stedendriehoek in 2030*. Retrieved on 8th of July 2017 from http://www.regiostedendriehoek.nl/leefomgeving/publicaties/nieuwe-energie-voor-de-stedendriehoek.pdf.
Selman, P. (2010). Learning to love the landscapes of carbonneutrality. *Landscape Research*, *35*, 157–171.
Sijmons, D., Hugtenburg, J., Feddes, F., & Van Hoorn, A. (2014). *Landscape and energy, designing transition*. Rotterdam, The Netherlands: NAi010 Publishers.
Stremke, S., & Koh, J. (2011). Integration of ecological and thermodynamic concepts in the design of sustainable energy landscapes. *Landscape Journal*, *30*(2), 194–213.
Stremke, S., & van den Dobbelsteen, A. (2013). *Sustainable energy landscapes; designing, planning and development*. Boca Raton, FL, USA: CRC Press (Taylor & Francis Group).
Stremke, S. (2015). Sustainable energy landscape: Implementing energy transition in the physical realm. In S. E. Jørgensen (Ed.), *Encyclopedia of environmental management* (pp. 1–9). Abingdon: Taylor & Francis.
Stremke, S., Kann, F. V., & Koh, J. (2012). Integrated visions (Part I): Methodological framework for long-term regional design. *European Planning Studies*, *20*(2), 305–319.
Stremke, S., Neven, K., Boekel, A., & Koh, J. (2012). Integrated visions (part II): Envisioning sustainable energy landscapes. *European Planning Studies*, *20*(4), 609–626.
Trutnevyte, E., Stauffacher, M., & Scholz, R. W. (2011). Supporting energy initiatives in small communities by linking visions with energy scenarios and multi-criteria assessment. *Energy Policy*, *39*, 7884–7895.
Urgenda (2015). *The Urgenda climate case against the Dutch government*. Retrieved October 15, 2015 from http://www.urgenda.nl/en/climate-case/.
Van den Dobbelsteen, A., Broersma, S., & Stremke, S. (2011). Energy potential mapping for energy-producing neighborhoods. *International Journal of Sustainable Building Technology and Urban Development*, *2*, 170–176.
Van der Horst, D., & Vermeylen, S. (2011). Local rights to landscape in the global moral economy of carbon. *Landscape Research*, *36*(4), 455–470.
Wang, Q., Mwirigi M'Ikiugu, M., & Kinoshita, I. (2014). A GIS-based approach in support of spatial planning for renewable energy: A case study of Fukushima, Japan. *Sustainability*, *6*, 2087–2117.
Weller, R. (2008). Planning by design: Landscape architectural scenarios for a rapidly growing city. *Journal of Landscape Architecture*, *3*(2), 18–29. http://dx.doi.org/10.1080/18626033.2008.9723401.
Yin, R. K. (2009). *Case study: Research, design and methods*. Thousand Oaks: Sage.